3P-19

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 493-494
6-8 December, 2010

Temperature distribution imaging in concave-shaped space from time-of-flight of acoustic wave by maximum likelihood expectation maximization algorithm
最尤推定－期待値最大化法による音波伝搬時間からの凹形状空間内温度分布の可視化

Ayumu Minamide[1, 2‡], Naoto Wakatsuki[1] and Koichi Mizutani[1]
([1]Univ. Tsukuba, [2]JSPS Research Fellow)
南出歩 [1, 2‡]，若槻尚斗 [1]，水谷孝一 [1] （[1]筑波大院・シス情工，[2]学振特別研究員 DC）

1. Introduction

Temperature distribution measurements are important in various fields[1)]. Thus, many kinds of measurement methods have been proposed. Among these methods, we have researched acoustic computerzed tomography (A-CT) with times of flight (TOF) of acoustic waves for the temperature distribution measurement in concave-shaped sapce[3)]. This method is based on the inverse Radon transform which is an analytical reconstruction technique.

However, it has also been clarified that this method is complicated and errors occur since projection data along sound paths muffled by the wall are treated as hollow projection. To solve these problems, we employ maximum likelihood expectation maximization (ML-EM) algorithm[3)], which is proposed to be used for A-CT in ref. 3. The ML-EM algorithm is one of the iterative reconstruction techniques originally proposed for positron emission tomography (PET)[4)]. This algorithm has an advantage against the hollow projection. We partially modify the algorithm to more suit for the temperature distribution. This algorithm is considered to be suitable for the measurement in the concave-shaped space.

2. Principles

Figure 1 illustrates the principle of the A-CT. In this figure, 3×3 cells and 6 sound paths are assumed. Solid lines show boundaries of the cells and dashed lines show the sound paths. Here, λ_j denotes reciprocal of sound velocity in the jth cell (m/s), D_{ij} denotes the length of ith path in jth cell (m), and τ_i denotes the TOF of ith path (s) (i = 1, 2,..., 6, j = 1, 2,..., 9). Here, in the PET and ref. 3, D_{ij} correspond to the detection probability. In this paper, as mentioned above, D_{ij} is defined as the length since TOFs are used. From these settings, the relationship between the reciprocal of sound velocity, length,

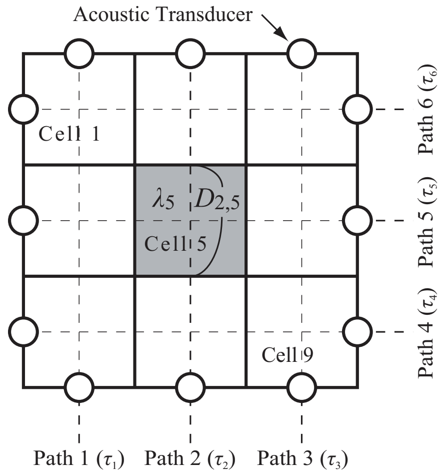

Fig. 1 Principle of the A-CT based on ML-EM where solid lines show boundaries of cells and dashed lines show sound paths.

and TOF of ith path is described as

$$\sum_{j=1}^{9} D_{ij}\lambda_j = \tau_i \cdot \tag{1}$$

Using the relationship of eq. (1) in ML-EM algorithm, λ_j (s/m) is calculated by the following equation,

$$\lambda_j^{(k+1)} = \frac{\lambda_j^{(k)}}{\sum_{i=1}^{6} D_{ij}} \sum_{i=1}^{6} \frac{D_{ij}\tau_i}{\sum_{l=1}^{9} D_{il}\lambda_l^{(k)}}, \tag{2}$$

where k denotes the iteration number. By the iteration, the solutions converge from initial solutions λ_j^0 ($\lambda_j^0 > 0$).By using the convergent solution λ_j, temperature in air T_j (°C) is obtained by the following equation,

$$T_j = 273.15 \cdot \left(\frac{1}{331.32^2} \lambda_j^{-2} - 1 \right) \cdot \tag{3}$$

Here, in this research, two kinds of termination conditions condition are mounted. One is a maximum iteration count K. When k becomes larger than K, the iteration of eq. (2) is terminated. The other is a modification tolerance ε (m/s). When a maximum modification variation between $\lambda_j^{(k+1)}$ and $\lambda_j^{(k)}$, i.e. $\max\left(\left|\lambda_j^{(k+1)} - \lambda_j^{(k)}\right|\right)$ becomes smaller than ε, the iteration is terminated.

---

minamide@aclab.esys.tsukuba.ac.jp
{mizutani, wakatuki}@iit.tsukuba.ac.jp

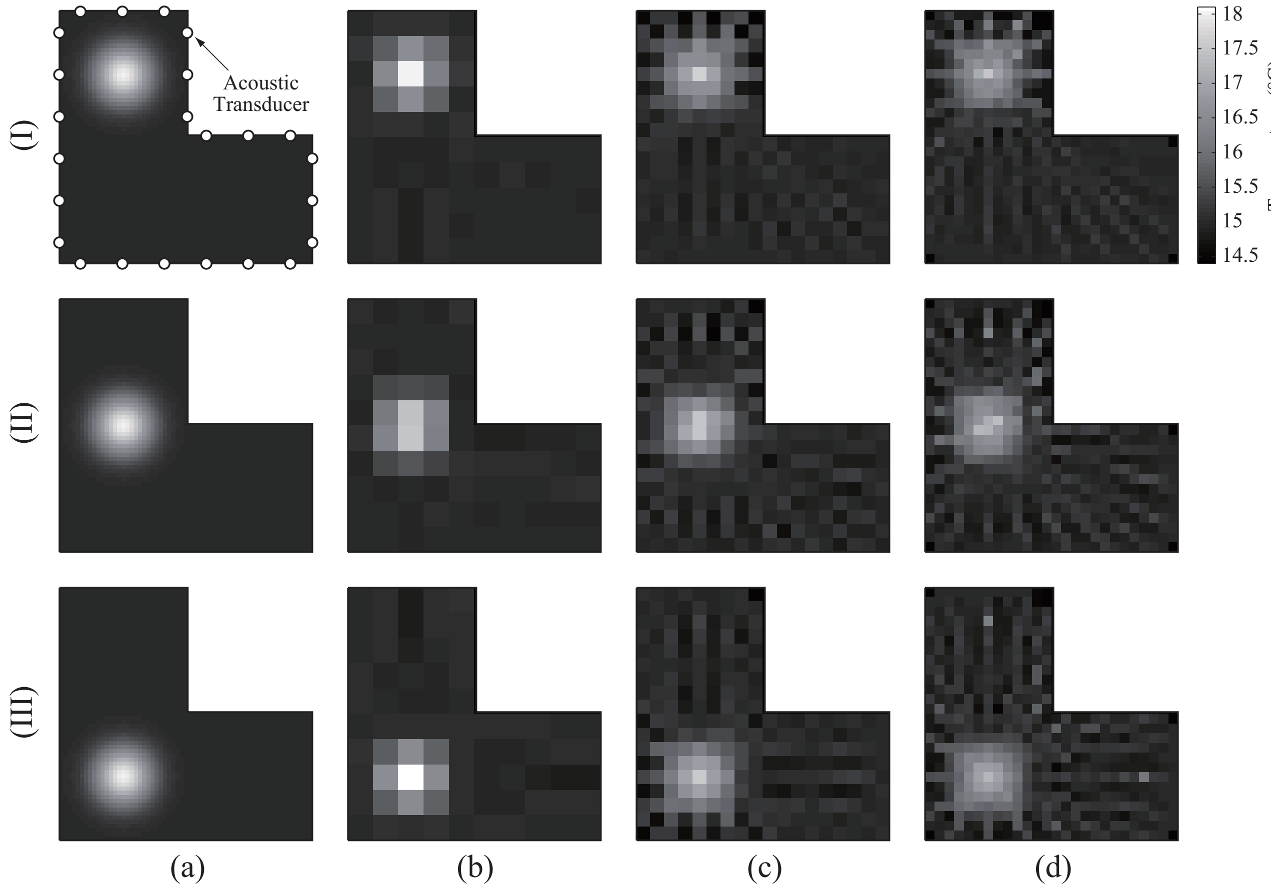

Fig. 3 Setting and reconstructed temperature distributions: (a) setting, (b) 10×10 cells, (c) 18×18 cells, (d) 26×26 cells.

3. Numerical simulations and discussion

By numerical simulations, we confirm usefulness and adequacy of our method. **Figure 2** shows setting and reconstructed temperature distributions. In the upper figure of Fig. 2(a), the transducer arrangement is shown. The setting distribution is given by a Gaussian function whose peak temperature is 18 °C and base temperature is 15 °C. By changing center of the Gaussian function, 3 distributions are managed. Figures 3(b) – 3(c) show reconstructed distributions whose cell numbers are 10×10, 18×18, and 26×26, respectively. Here, in the Figs. 3(c) and 3(d), cells where sound paths do not propagate exist because the cell size is small. These cells are shown in black cells.

As shown this figure, the distributions are reconstructed. However, errors increase as the number of cells increase. This is attributable to the small number of sound paths in the cell. By the increase of cells, cells where a small number of sound paths propagate considered to increase. From this reason, the solution is considered not to be well solved.

4. Conclusions

We managed the A-CT based on ML-EM algorithm with TOFs. By the numerical simulations, usefulness and adequacy of our method was confirmed. By our method, adequate reconstructed distributions were simply obtained.

Acknowledgment

This work was supported by Grand-in-Aid for JSPS Fellows (No. 21·998) from the Japan Society for the Promotion of Science.

References

1. G. K. Spanomitsios: J. agric. Engng Res. **80** (2001) 251.
2. A. Minamide, N. Wakatsuki, and K. Mizutani: Proc. 17th Int. Cong. Sound. Vib. (2010) 134 (CD-ROM).
3. H. Fan, H. Yanagida, Y. Tamura, S. Guo, T. Saitoh, and T. Takahashi: Jpn. J. Appl. Phys. **49** (2010) 07HC12.
4. L. A. Shepp and Y. Vardi: IEEE Trans. Med. Imag. **1** (1982) 113.